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A Scenario Analysis of the Potential Effects of Decarbonization on the Profitability of the Energy-Intensive and Natural-Resource-Based Industries

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Abstract
The decarbonization of the energy-intensive and natural-resourced-based industries is associated with large economic costs. In this paper, I explore how decarbonization may affect the profitability and market value of these industries and their ability to attract capital to fund their decarbonization. I also discuss the possibility of compensating for the investment costs through higher prices and enhanced productivity. I answer these questions using scenario analysis with a focus on the industries in the European Union and the United States. I find that the effects on profitability are likely to be modest despite relatively high investment costs.

Keywords: decarbonization; energy-intensive; industry; profitability; investment
JEL codes: L6; L7; Q54

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1. Introduction

The energy-intensive and natural resource-based industries (ENRIs)[2] are among the most carbon-intensive industries (Andersson, 2020). While a decarbonization of these industries is technically possible (for a review of technical options, see e.g. de Bryn et al., 2020; Gerres et al., 2019; IEA, 2020b), it will requires large capital investments in new and sometimes not yet fully developed production processes (IEA, 2020a). Traditionally, investments have generated economic benefits, such as improved productivity or enlarged production capacity, which in turn have increased revenues sufficiently to finance the investments. However, for the ENRIs, the economic benefits from investments in green carbon-free technologies are relatively small (Åhman and Nilsson, 2015; Åhman et al., 2017; Bataille et al., 2018; de Pee et al., 2018). Green investments are necessary to reduce greenhouse gas emissions but are unlikely to generate substantial new revenues for a firm or reduce its production costs significantly. Without an increase in revenues or a cut in costs, the profitability and market value of the ENRIs decline, which in turn reduces the willingness of investors to invest in these industries. This raises the question of whether the ENRIs will be able to raise sufficient private capital to fund their investments in green technologies and to what extend they will require public support.

The purpose of this paper is to explore the potential financial consequences of a decarbonization of ENRI on their profitability and thus their ability to attract private capital. The decarbonization process of ENRI is still in an early phase and there remains several unknowns regarding different technical solutions, their efficiency, and costs. This is reflected in the wide range of estimated investments costs in the literature, which spans from a few hundreds of billions of dollars to trillions of dollars globally (D'Aprile et al., 2020; Gielen et

[2] I define the ENRIs as the following NACE Revision 2 (ISIC Revision 4) industries: mining (B), wood and paper products (C16–C18), chemicals and chemical products (C22–C23), and fabricated metals and metal products (C24–C25).

al., 2020; Hall et al., 2017; Nykvist et al., 2020). The paper is thus explorative and considers a set of different scenarios based on different assumptions regarding potential costs and their impacts on the profitability of ENRI. The analysis extends beyond previous estimates of the direct investment cost to also consider the impact of capital loss (stranded assets) and heightened uncertainty about future production costs and revenues as a result of the decarbonization process. Previous paper mostly focuses on the direct investment costs, ignoring the other effects a decarbonization may have on the profitability of ENRI. The paper ends by discussing the possibility to compensate for the decarbonization costs through higher prices and/or enhanced productivity, and the overall implications for ENRI's possibility to privately finance its decarbonization. I focus on the aggregate effects using industrial level data from the United States and the European Union.

The results shows that higher uncertainty is the main factor, which may affect ENRI's ability to attract external funding for its decarbonization. Relatively high investment costs and/or capital loss reduces the profitability, but these effects are relatively small compared to the uncertainty effect. Overall, the results suggest that ENRI is likely to be able to privately fund most of its decarbonization even under the assumption of high investment and capital loss costs, provided that the levels of uncertainty about future revenues does not increase.

The rest of the paper is organized as follows. Section 2 outlines how decarbonization may affect the ENRIs financially. Section 3 introduces the data on which the scenarios build. Section 4 outlines the scenarios. Section 5 presents the result of the scenario analysis. Section 6 concludes the paper.

2. Transition finance and the costs of decarbonization

Transition finance is a growing research field. It studies how to "*optimise access to finance for sustainable development*" (OECD, 2019). One part of the literature concerns the role of the private sector vs the public sector at different stages of the innovation and investment cycle (Hood, 2011; OECD, 2017; de Bryn et al, 2020). Another part of the literature focuses on how to incentivize the private sector to shift its investments from carbon-intensive to green technologies. Private/public disclosure initiatives such as the Task Force on Climate Related Financial Disclosures (TCFD), and government regulations such as the EU's Corporate Sustainability Reporting Directive (CSRD), and the EU Taxonomy are examples of initiatives aimed at steering financial flows away from carbon intensive investments into low or no carbon technologies (see e.g. EU, 2020; 2021; TCFD, 2017).

A key challenge for the financial system is to the fund the necessary investments to achieve a decarbonization of ENRI. Investors' willingness to invest in an industry depends on the industry's market value, which is an expression of its present and future expected profitability. Decarbonization of the ENRIs is likely to have a substantial, and mostly negative, impact on their profitability, not least in the short term. If the costs are large and the benefits small, the financial system may struggle to fund the decarbonization projects. There are primarily three channels through which decarbonization affects ENRI's profitability: The first channel is the net *investment channel*, which captures the net cost of investing in new carbon-free green capital. There are two potential parts to this cost: the first is due to green capital being relatively more costly than carbon-intensive capital; the second concerns the premature replacement of the existing capital before it reaches the end of its expected lifespan. All capital depreciates over time and needs replacement. In theory, one option to decarbonize the ENRIs is to replace carbon-intensive capital with green capital over time as it depreciates. As long as the green capital is not more expensive than the existing carbon-intensive capital, such a slow decarbonization process would not increase the net cost of the industries. However, the ENRIs have long investment innovation cycles spanning several decades (IEA, 2020a; Wessling et al., 2017), which create the risk that the decarbonization processes will become misaligned with the industries' normal investment cycles (IEA, 2020b), especially if the decarbonization is to be completed as early as the middle of the century. The ENRIs are likely to face a scenario in which they have to replace fully functional carbon-intensive capital ahead of the end of its expected lifespan, which imposes a net investment cost for them (Gerres et al., 2019; IEA, 2020a). A further complication is that decarbonization may require the complete replacement of the existing production processes, making it impossible to decarbonize in small steps over several years. Instead, there will be a large initial investment early in the decarbonization process.

The second channel is the *capital loss channel* or stranded asset channel. As the economy shifts from carbon-intensive to green technologies, the market value of carbon-intensive capital declines. In the most extreme case, it may become worthless beyond its scrap value. This creates a capital loss for the firm as the value of its existing assets declines, negatively affecting the value of the industry. The third channel is the *uncertainty channel*. The market value of the ENRIs depends on the present value of their present and future expected net profits (profits after costs and taxes). The present value is calculated using a discount factor that captures investors' time preferences, risk preferences, level of risk aversion, and uncertainty about the future. The higher the level of uncertainty, the higher the discount rate (Butler and Schacter, 1989; Traeger, 2014; Weisbach and Sunstein, 2009). Decarbonization is associated with several uncertainties, including technological uncertainty, political uncertainty, and market uncertainty (TCFD, 2017). Technological uncertainty includes uncertainty about the possibility of developing green technologies and whether it is possible to scale emerging technologies. Political uncertainty includes uncertainty about whether policymakers will implement the needed legislative changes and invest in the necessary energy infrastructure to enable a shift to green technologies. Market uncertainty refers to how the demand for the ENRIs' output will develop in the future. The decarbonization of the economy may involve a reduction in the demand for new virgin materials as the economy transitions from primarily linear production flows to, at least, a more circular flow (Cooper et al., 2020; Van der Voet et al., 2020; Winans and Deng, 2017). This implies a decrease in the output levels for the ENRIs, leading to lower profit levels ceteris paribus. As investors are faced with heightened levels of uncertainty, they may increase the discount rate, which will lead to a lower market value of the industries.

2.1 User cost of capital

To model the effects of decarbonization on the ENRIs' profitability, and hence their market value, this research relies on the user cost of capital theory (see e.g. Jorgenson et al., 2005; Romer, 2019). The return on installed capital is determined by three factors: the nominal net capital compensation, the speed of depreciation of capital stock, and the capital gains/losses resulting from a change in the market value of capital. The level of net capital compensation depends on the productivity of the capital, the operating costs of the capital, and the net taxes. The more productive the capital is, the higher the capital compensation is. The level of depreciation depends on how quickly the capital stock is exhausted. Capital losses/gains are associated with changes in the market value of the installed capital. A shift toward new production methods will cause some assets to become stranded and thus generate a capital loss for the firm.

Specifically, the real net rate of return is given by

$$r_{j,t} = \frac{CAP_{j,t} + \sum_{\kappa}(p_{\kappa,j,t} - p_{\kappa,j,t-1})K_{\kappa,j,t} - \sum_{\kappa}\delta_{\kappa,j}p_{\kappa,j,t}K_{\kappa,j,t}}{\sum_{\kappa}p_{\kappa,j,t-1}K_{\kappa,j,t}} \tag{1}$$

where r is the real rate of return, CAP is the net nominal capital compensation in fixed prices, and K is the total amount of installed capital of capital type κ. Here, I assume that there is potentially more than one type of capital, such as structures, machinery, computer systems, and so on. Each unit of capital is assumed to be equally productive and generate the same income in equilibrium. The depreciation rate is represented by δ_{κ} and may vary depending on the capital type. The market value of capital is denoted by *p*. The subindex *t*=1,…,*T* denotes the time, and *j*=1,…, *J* denotes the industry.

The numerator in (1) shows the net real capital compensation considering capital compensation, capital depreciation, and capital gains/losses. The present market value of industry *j* is given by the present and future expected profits of the industry,

$$MV_{j,t} = E_t\left[\sum_{t=1}^{T}\left(\frac{1}{1+\rho_t}\right)^{t-1}\left(CAP_{j,t} + \sum_\kappa\left(p_{\kappa,j,t} - p_{k,j,t-1}\right)K_{\kappa,j,t} - \sum_\kappa \delta_{\kappa,j}p_{\kappa,j,t}K_{\kappa,j,t}\right)\right] \qquad (2)$$

where E is the expectation operator and ρ_t is the discount rate, which is potentially time dependent. It reflects the investors' time preferences, level of risk aversion, and uncertainty about the future. The more risk averse the investors are, or the greater the uncertainty about the future, the higher the depreciation rate will be, implying that a unit of future net capital compensation has a lower value than a unit of net capital compensation today.

By using equations (1) and (2), I can explore how decarbonization affects the profitability and market value of the ENRIs. It is possible to model the net investment cost as changes in the depreciation rate. A higher depreciation rate captures both a higher cost of green capital compared with carbon-intensive capital and a misalignment between the decarbonization process and the industries' normal investment cycles. The capital loss is modeled by reducing the value of the existing capital. Uncertainty is modeled by changing the value of the discount rate in equation (2).

It is also possible to investigate how large increases in net nominal capital compensation (*CAP*) are necessary to compensate for the decarbonization costs and whether it would be possible to generate a sufficiently large increase in net nominal capital compensation through higher prices or improved productivity.

3. Data and descriptive statistics

I focus my analysis on the ENRIs in the European Union and the United States. They represent two advanced economies with some of the most developed ENRIs in the world. In addition, both the EU and the US have signed the Paris climate agreement committing to substantial emission reductions by 2050. In my scenarios, I focus on aggregate effects rather than firm-level effects and use industry sector data as my primary interest is in the possibility of decarbonizing the entire industries rather than individual firms' specific conditions.

Data are collected from the EU KLEMS database,[3] which contains detailed and harmonized data at the industrial level on capital and labor inputs, gross output, value added, and prices. The economy is divided into 35 manufacturing and service industries. I define ENRIs as the following five material-producing and energy- and carbon-intensive industries: mining (NACE Revision 2 code B), wood and paper products (C16–C18), chemicals and chemical products (C20), rubber and plastic products (C22–C23), and basic metals and fabricated metal products (C24–C25). The database covers the period 1997 to 2016, and I use the entire period to calculate the key statistics on depreciation rates, capital gains/losses, prices, and productivity on which I build my scenarios.

This analysis of the EU is limited to the relatively developed EU14 countries (the EU15 minus the United Kingdom). Newer member states from primarily central and eastern Europe are excluded as they, at least for part of the sample period, were transitioning from state-planned to full market economies. Unfortunately, some key statistics are missing for Belgium, Spain, Ireland, and Portugal, so my sample consists of 10 EU countries (EU10): Austria, Denmark, Germany, Greece, Finland, France, Italy, Luxembourg, the Netherlands, and Sweden.

[3] The database is operated by the Vienna Institute for International Economic Studies, and it is funded by the European Commission DG Economic and Financial Affairs.

3.1 Capital stock and depreciation rates

The database divides the capital stock into six types of fixed capital: non-residential structures, other machinery, transport equipment, communication equipment, computing equipment, and software. Table 1 contains the level of capital employed in each industry by type. The numbers are expressed in millions of EUR for the EU10 and millions of USD for the United States. The distribution of capital type in the EU10 is similar to that in the US except for mining, for which the US stands out with large values in non-residential structures. Although the differences are small, all the US industries tend to employ less communication, computing, and software capital than the EU. The distribution of capital by type is similar across all the industries except the mining industry, of which non-residential structures make up a relatively larger share, not least in the United States. Non-residential structures and other machinery dominate with a combined share of nearly 90 percent in all the industries.

Table 1: Capital stock and distribution of capital investments in the ENRIs, 2016, in millions of local currency units.

	Non-residential structures	Other machinery	Transport equipment	Communication equipment	Computing equipment	Software
				Mining (B)		
EU10	122 665	52 211	2 014	489	1 431	973
	(68%)	(29%)	(1%)	(0%)	(1%)	(1%)
US	1 663 676	139 324	46 723	5 163	2 141	3 331
	(89%)	(7%)	(3%)	(0%)	(0%)	(0%)
				Wood and paper products (C16–C18)		
EU10	52 532	82 630	3 628	2 690	1 925	3 326
	(36%)	(56%)	(2%)	(2%)	(1%)	(2%)
US	82 815	108 199	2 222	965	1 369	3 498
	(42%)	(54%)	(1%)	(0%)	(1%)	(2%)
				Chemicals and chemical products (C20)		
EU10	49 970	94 062	4 177	2 138	957	4 494
	(32%)	(60%)	(3%)	(1%)	(1%)	(3%)
US	166 161	184 029	1 352	4 076	2 609	5 686
	(46%)	(51%)	(0%)	(1%)	(1%)	(2%)

	Rubber and plastic products (C22–C23)					
EU10	57 991 (34%)	98 224 (58%)	5 392 (3%)	1 135 (1%)	2 319 (1%)	3 924 (2%)
US	72 120 (41%)	97 777 (55%)	2 755 (2%)	1 141 (1%)	1 051 (1%)	2 313 (1%)
	Basic metals and fabricated metal products (C24–C25)					
EU10	77 461 (31%)	151 589 (61%)	7 770 (3%)	2 627 (1%)	1 910 (1%)	5 425 (2%)
US	130 291 (40%)	182 510 (57%)	4 833 (2%)	1 185 (0%)	984 (0%)	2 323 (1%)

Source EU KLEMS.

Table 2 presents the depreciation rates for each type of capital according to the estimates by the EU KLEMS. The depreciation rates vary across industries but are assumed to be the same across countries. Communication equipment, computing equipment, and software have the highest depreciation rate at 0.315, implying that this type of capital is completely replaced roughly every third year. Non-residential structures have the lowest depreciation rate: 0.024 for the mining industry and 0.033 for the other ENRIs. One unit of capital is fully replaced every 30 to 40 years. There is a somewhat greater difference among the industries when it comes to the depreciation rate for other machinery, which ranges from 0.104 (chemicals and chemical products) to 0.129 (mining).

Table 2: Depreciation rates estimated by the EU KLEMS.

	Mining (B)	Wood and paper products (C16–C18)	Chemicals and chemical products (C20)	Rubber and plastic products (C22–C23)	Basic metals and fabricated metal products (C24–C25)
Non-residential structures	0.024	0.033	0.033	0.033	0.033
Other machinery	0.129	0.106	0.104	0.112	0.108
Transport equipment	0.170	0.173	0.181	0.191	0.191
Communication equipment	0.115	0.115	0.115	0.115	0.115
Computing equipment	0.315	0.315	0.315	0.315	0.315
Software	0.315	0.315	0.315	0.315	0.315

Source: EU KLEMS.

According to these statistics, the long investment cycles cited in the literature (see e.g. IEA, 2020a; Wessling et al., 2017) is due to non-residential structures. For all other types of capital, one unit is replaced every third to tenth year. However, as different types of capital are interrelated, the choice of machinery and software capital is partially dependent on the type of non-residential capital that is employed by the industry. Although it is possible to replace other machinery on a regular basis, a complete technological shift from carbon-intensive technology to green technology is potentially prevented by the existing non-residential structures. A major technological shift in machinery may require simultaneous updating of the non-residential structures.

3.2 Capital gains/losses and value-added growth

On average, during the sample period, most industries experienced a capital loss, that is, a decline in the real value of their installed capital; see Table 3. The real value of all types of capital declined on average, except non-residential structures, for which it increased, except in the wood and paper industry. The value of other machinery capital declined by almost 1 percent per year, while communication and computing equipment capital decreased by between 3 and 7 percent per year. Since the latter types of capital account for a small share of the total capital stock, the overall capital loss is between 0 and 1 percent per year for all the industries.

Table 3: Average yearly real capital gains/losses, percentage, 1996–2016.

	Mining (B)	Wood and paper products (C16–C18)	Chemicals and chemical products (C20)	Rubber and plastic products (C22–C23)	Basic metals and fabricated metal products (C24–C25)
Non-residential structures	+1.0	-1.1	+0.3	+0.3	+0.5
Other machinery	-0.9	-0.7	-0.9	-0.8	-0.7
Transport equipment	-0.8	-1.0	-1.1	-1.0	-0.8

Communication equipment	-3.7	-4.4	-3.5	-3.9	-4.1
Computing equipment	-7.3	-6.5	-6.3	-7.0	-6.7
Software	-1.8	-1.5	-0.5	-0.5	-1.4

Source EU KLEMS.

The decline in the value of installed capital can potentially be explained by the maturity of the industries. While the ENRIs were a key driver in the early stages of industrialization (Perez, 2002), their relative importance gradually declined over time as other industries became the drivers of economic development: first the manufacturing industries and then the service industries. The declining economic importance of the ENRIs is reflected in their modest value-added growth during the sample period. The average yearly growth rate in value added is less than 1 percent, except for that in the mining industry, which is 2 percent; see Table 4. In the wood and paper industry, the growth was even negative (-0.3 percent). As a comparison, the total EU10 economy grew by 1.4 percent per year during the period, and the US economy grew by 2.0 percent per year.

Table 4: Average yearly value-added growth, real capital productivity, and relative prices, 1998–2016

	Mining (B)	Wood and paper products (C16–C18)	Chemicals and chemical products (C20)	Rubber and plastic products (C22–C23)	Basic metals and fabricated metal products (C24–C25)
Real value added growth	+2.0	-0.3	+0.8	+0.7	+0.8
Real capital productivity	+4.4	+0.8	+2.1	+1.6	+2.6
Relative prices	-1.9	-1.4	-0.9	-0.8	-0.5

Source: EU KLEMS.

Two key factors determining the level of capital compensation are capital productivity growth (capital compensation per unit of installed capital) and relative prices (prices compared with the aggregate price level). Greater productivity increases capital compensation, as do higher relative prices. The average productivity growth is relatively high, between 0.8 percent (wood and paper) and 4.4 percent (mining). The economy-wide average is 1.8 percent. The possibility of enhancing productivity despite the modest growth in value added is positive from a decarbonization point of view as it implies that modest future growth for materials, as the economy becomes more circular, will not severely limit the ENRIs' ability to enhance their productivity and maintain a relatively high level of net nominal capital compensation.

The relative prices declined across all industries by between 0.5 percent (basic and fabricated metals) and 1.9 percent (mining). The decline in relative prices does not imply that the industries cannot increase their prices in the future; it only indicates that the relative prices, on average, decreased between 1998 and 2016.

4. Scenarios

There are too many unknown factors to predict accurately the effects of decarbonization on the profitability and market value of the ENRIs.[4] The investment cost, the size of the capital losses, and the changes to the discount rate are all unknown. An alternative approach when the future is too uncertain to forecast the outcome is scenario analysis. The purpose of a scenario is not to forecast the outcome. By varying the underlying assumptions, it is possible to explore various factors' impact on the outcome, determine which factor(s) have the greatest impact on the results, and map the space of potential outcomes (Peterson et al., 2003; van Notten, 2006). Scenarios are widely used within a range of fields in which the degree of uncertainty prevents

[4] See e.g. King (2016) and Kay and King (2020) for a discussion on so-called radical uncertainty.

accurate forecasting of the future, such as climate (van Vuuren et al., 2011) and economics (e.g., Carpos et al., 2014).

I build my scenarios around variations in the investment cost (depreciation rate), the capital loss, and the discount rate. I also discuss the possibility of increasing the capital compensation through productivity and relative price increases to compensate for these costs. An additional factor that I consider and that affects the outcome of my scenarios is the length of the transition period from carbon-intensive to green capital. In the scenarios that I develop, the cost of decarbonization is limited to the transition period. The industries, for simplicity, are assumed to revert to the same level of profitability after the transition as before the transition. Consequently, the longer the transition period, the higher the costs.[5] I consider two transition periods: a 5-year period and a 10-year period. Extending the transition period beyond 10 years has no major impact on the results as all capital, except non-residential structures, is fully relaced within a 10-year period; see the depreciation rates in Table 2. For simplicity, I also assume that the output and the total size of the capital stock remain constant over time.

4.1 Depreciation rate

The net investment cost, in excess of the investment cost without decarbonization, is modeled as an increase in the depreciation rate during the transition period. I consider three increases in the depreciation rate: 25 percent, 50 percent, and 100 percent (i.e. doubling of the depreciation rate). At the beginning of the transition period, the depreciation rate increases. The ENRIs are forced to replace each unit of carbon-intensive capital that depreciates with one new unit of green capital. This imposes a higher cost on the ENRIs, which represents the net investment cost. Green capital is not subject to a higher depreciation rate, which implies that the net investment cost declines over time as carbon-intensive capital is replaced by green capital. This

[5] Extending the transition period beyond 10 years has no major impact on my results due to the size of the depreciation rates. All capital except non-residential structures is fully replaced within a 10-year period.

construction of the modeling of the net investment cost also ensures that the cost is higher at the beginning of the transition period and declines thereafter. It is zero once the transition period has ended.

Based on these assumptions, the total investment cost varies between 3 and 7 percent of the industries' total capital stock with a 25 percent increase in the depreciation rate, between 6 and 13 percent with a 50 percent increase in the depreciation rate, and between 19 and 30 percent of the total capital stock with a doubling of the depreciation rate; see Table 5. In nominal terms, these numbers correspond to a total transition cost for the ENRIs in the EU10 of between 55 and 180 billion EUR for the 5-year transition period and between 85 and 250 billion EUR for the 10-year transition period. In the US, the corresponding numbers are 125 billion to 595 billion dollars for the 5-year period and 215 to 665 billion dollars for the 10-year period. The US numbers are higher due to the relatively large number of non-residential structures in the mining sector. These investment costs are similar to, or potentially on the lower side of, some of the few estimates in the literature (Gielen et al., 2020; Hall et al., 2017; Nykvist et al., 2020). However, those studies estimated the gross cost and did not consider the investment cost due to depreciation that the ENRIs would face even without decarbonization. My investment costs are thus clearly in line with the estimates in the literature.

Table 5: Cost of decarbonization in relation to the size of the capital stock for different increases in the depreciation rate.

Increase in depreciation rate	Mining (B)		Wood and paper products (C16–C18)		Chemicals and chemical products (C20)		Rubber and plastic products (C22–C23)		Basic metals and fabricated metal products (C24–C25)	
	EU10	US	EU10	US	EU10	US	EU10	US	EU10	US
5-year transition period										
25%	7	3	6	6	6	6	7	7	7	7
50%	13	6	12	12	12	11	12	12	12	12
100%	21	11	20	21	21	20	21	21	21	21
10-year transition period										
25%	10	6	10	10	10	10	10	10	10	10
50%	18	11	18	18	18	17	18	18	18	18
100%	27	19	28	30	29	29	29	29	29	30

4.2 Capital losses

I model capital losses as a reduction in the value of the installed capital. I consider three sizes of loss: i) no cost; ii) a 1 percent per year additional decline in the value of carbon-intensive capital; and iii) a 5 percent per year additional decline in capital-intensive capital. Green capital is not subject to any capital losses. With a 1 percent yearly decline, 1 unit of carbon-intensive capital will lose 5 percent of its value after 5 years and 10 percent after 10 years. With a 5 percent yearly reduction in the value, the capital loss is 23 percent after 5 years and 40 percent after 10 years.

To calculate the capital losses, I divide the capital stock existing at the beginning of the transition period into two parts: i) the carbon-intensive capital, which will be replaced at the end of the transition period; and ii) the part of the capital stock that will remain after the transition. The additional capital loss is only calculated for the capital that will be replaced during the transition. The rest of the capital stock is assumed to follow the historical averages.

The size of the capital loss is thus the highest at the beginning of the transition period before decreasing to zero as the transition period progresses.

4.3 Discount factor—uncertainty

Empirical estimates of the discount rate have shown that it varies over time and across actors (see e.g. Gollier and Hammitt, 2014), with most estimates falling within the range of 1 to 7 percent when it comes to the discounting of financial flows. Some estimates have shown that the discount rate tends to be in the lower range over longer time horizons (Giglio et al., 2015). However, Blyth et al. (2007) found that investors applied a higher discount rate to investments in carbon-intensive energy production due to policy-related transition risks. I consider three discount rates, 3 percent, 5 percent, and 10 percent. The first two rates are within the range of most empirical estimates, while the 10 percent level is chosen as an extreme value that captures the situation of heightened uncertainty about future profits. With a 3 percent discount rate, the value of 1 unit of profit 10 years in the future has the same value as 0.74 units today, and 1 unit of profit in 20 years' time has the same value as 0.55 units today. With discount rates of 5 percent and 10 percent, the corresponding numbers are 0.61 (10 years) and 0.38 (20 years) and 0.39 and 0.15, respectively.

5. Results

The results section is divided into three parts. First, I discuss the impact of the investment cost and capital loss individually on the yearly rate of return. Second, I develop three scenarios—a low-cost, a medium-cost, and a high-cost scenario—in which I combine the investment and capital loss and explore the impact of the discount factor on the market value of the industry. Third, I discuss the possibility of compensating for the costs through higher prices and/or higher capital productivity.

5.1 Investment cost

The impact of the investment cost on the rate of return on installed capital is illustrated in Figure 1 (EU10) and Figure 2 (US). Each figure consists of five panels, one for each industry. Every panel contains three curves, representing the cost of a 25 percent increase in the depreciation rate, a 50 percent increase in the depreciation rate, and a 100 percent increase during the transition period. The results are shown in relation to the value of capital stock, that is, as

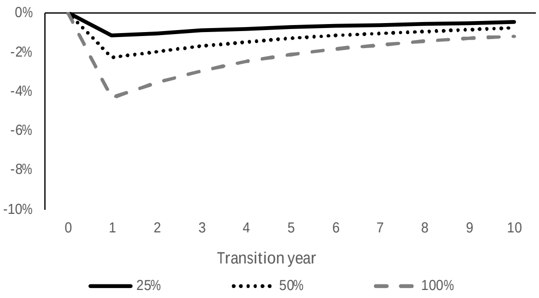
$$-\frac{\sum_{\kappa} \Delta\delta_{\kappa,j} p_{\kappa,j,t} K_{\kappa,j,t}}{\sum_{\kappa} p_{\kappa,j,t-1} K_{\kappa,j,t}}, \quad (3)$$

where $\Delta\delta$ indicates the change in the depreciation. A negative value of 1 percent in the figures corresponds to a 1 percentage point decline in the rate of return compared with the case of no net investment costs. The transition begins in period 1, and each figure maps the cost for 10 years. The cost for the 5-year transition period is the same as that for the 10-year period for the first 5 years by assumption. After 5 years, the costs are zero by assumption. For the 10-year transition period, the costs are zero after 10 years. By construction, the largest cost occurs at the beginning of the transition period. The cost decreases as more and more carbon-intensive capital is replaced by green capital.

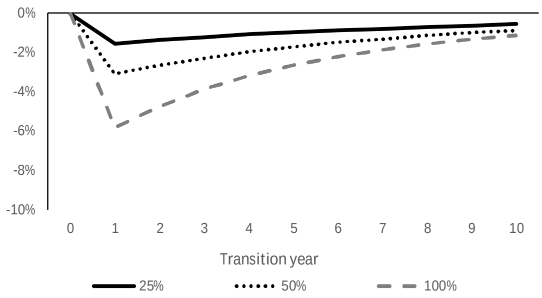
As can be seen from the figures, the impact of the investment cost is similar across industries, except for the mining industry, in which the cost is relatively smaller. This difference is caused by the relatively larger share of non-residential capital in the mining industry, which reduces the average depreciation rate and thus the investment cost. During the first year, an increase in the depreciation rate of 25 percent reduces the rate of return by nearly 2 percentage points (1.5 for the mining industry). The return then slowly increases toward the pre-decarbonization level. An increase in the deprecation rate of 50 percent reduces the profitability by 3 percent in the first year (2.5 percent for the mining industry), and a doubling of the depreciation rate causes a decline in the rate of return by nearly 6 percent in the first year (4.5

percent in the mining industry). Assuming that the rate of return on installed capital in the ENRIs is close to the economy-wide average of 3 percent in real terms,[6] an increase in the depreciation rate of 50 percent or more is necessary to eliminate the industries' profitability in the first transition year. As an increase in the depreciation rate of 50 percent implies that between 10 and 20 percent of the existing capital stock will be replaced in the decarbonization process, my results indicate that even a relatively large investment cost does not push the industry into negative returns in the first year, when the investment cost is the highest. Overall, these results indicate that the net investment costs need to be relatively high for the ENRIs to maintain positive profitability during each year ceteris paribus. However, the profitability is reduced, which decreases the market value of the industries.

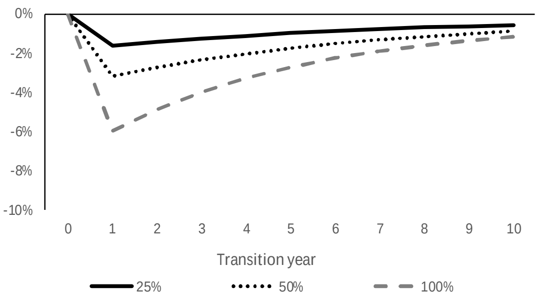
[6] This estimate is based on my own calculations using equation 1 and data from the EU KLEMS database.



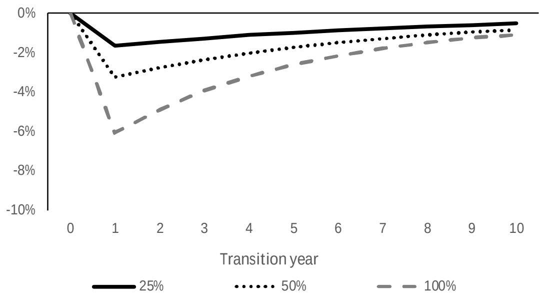
Panel A: Mining



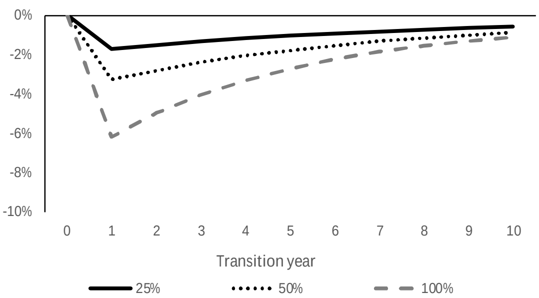
Panel B: Wood and paper products



Panel C: Chemicals and chemical products

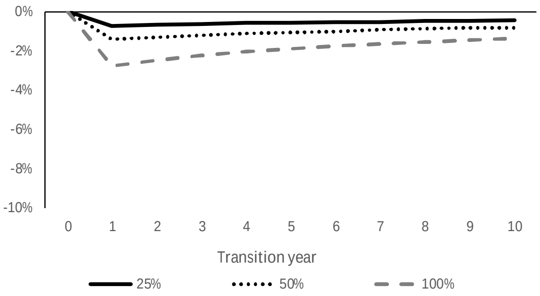


Panel D: Rubber and plastics

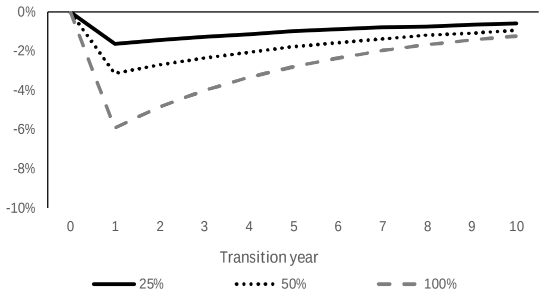


Panel E: Metals and fabricated metal products

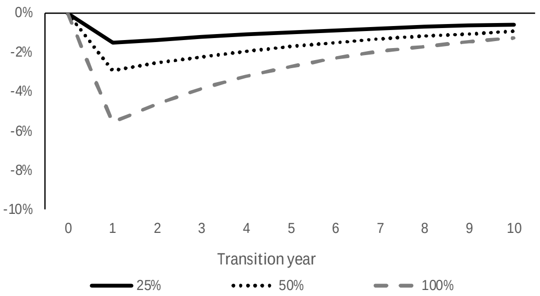
Figure 1: Costs of a higher depreciation rate in relation to the total capital stock, EU10.



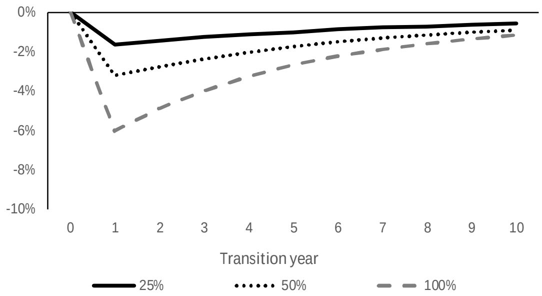
Panel A: Mining



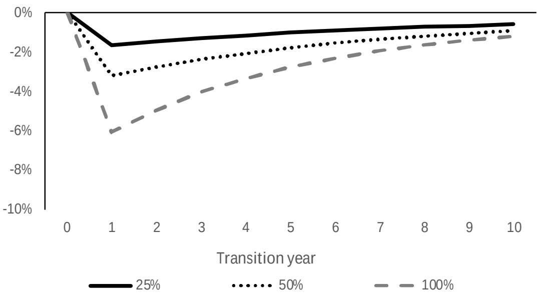
Panel B: Wood and paper products



Panel C: Chemicals and chemical products



Panel D: Rubber and plastics



Panel E: Metals and fabricated metal products

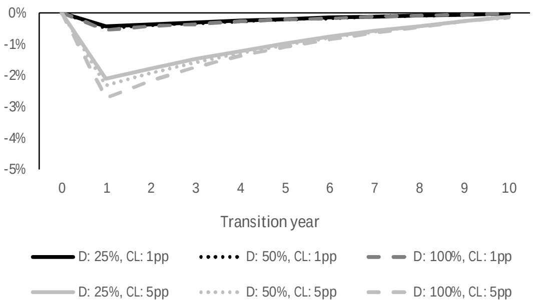
Figure 2: Costs of a higher depreciation rate in relation to the total capital stock, US.

5.2 Capital losses

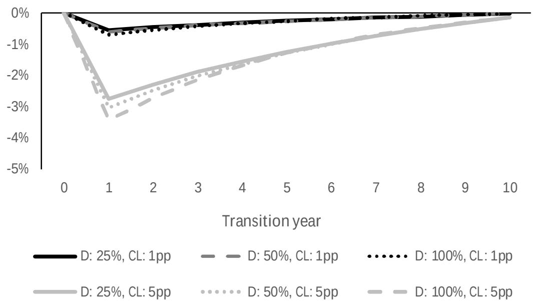
The size of the capital loss depends on the length of the transition period. The results are thus presented in two figures each for the EU10 and the US. Figures 3 (10-year transition period) and 4 (5-year transition period) contain the results for the EU10, and Figures 5 and 6 present the corresponding results for the US. The results for the investment costs are illustrated in relation to the size of the capital stock and thus the impact on the rate of return on installed capital in each year during the transition,

$$\frac{\sum_{\kappa}(p_{\kappa,j,t}-p_{k,j,t-1})K_{\kappa,j,t}}{\sum_{\kappa}p_{\kappa,j,t-1}K_{\kappa,j,t}}. \tag{4}$$

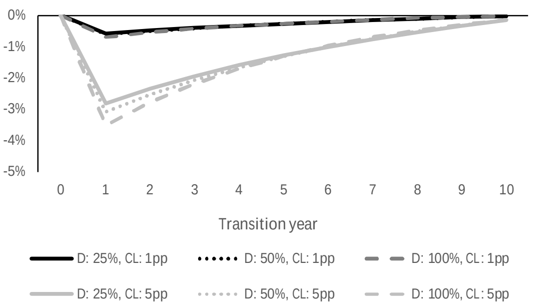
The capital loss is obviously larger for the longer transition period, during which more carbon-intensive capital is replaced by green capital. Compared with the investment cost, the capital loss cost is relatively small. For a 1 percent decline in the value of capital per year, the capital loss reduces the profitability by less than 1 percentage point irrespective of the industry. The effect increases to between 3 and 4 percentage points for the higher 5 percent decline in the value of carbon-intensive capital. For the mining industry, the cost is slightly lower as less capital is relaced due to the way in which the investment cost is modeled.



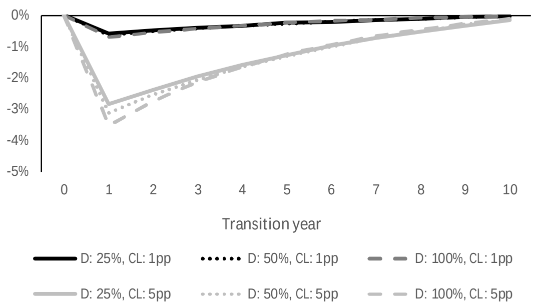
Panel A: Mining



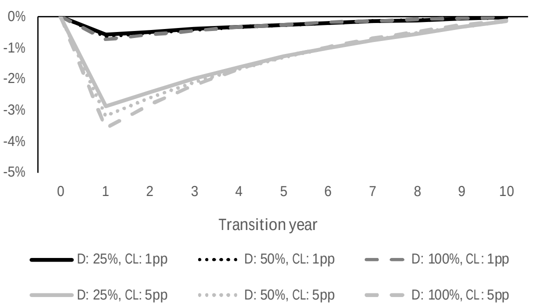
Panel B: Wood and paper products



Panel C: Chemicals and chemical products



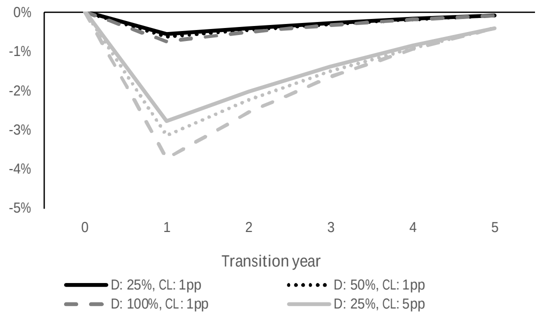
Panel D: Rubber and plastics



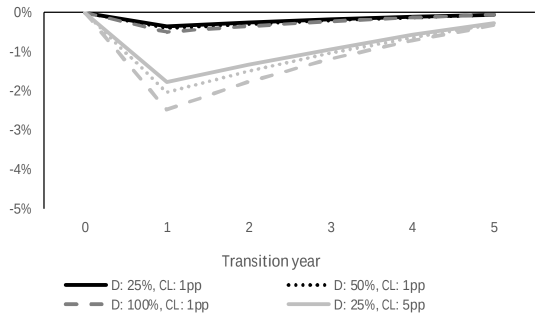
Panel E: Metals and fabricated metal products

Figure 3: Effects of capital losses, 10-year transition period, EU10.

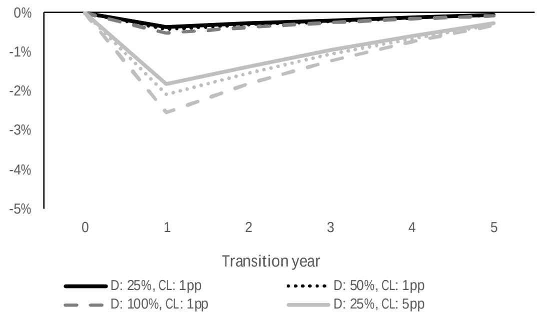
Note: D denotes an increase in the depreciation rate, and CL denotes a percentage point decline in the value of installed capital.



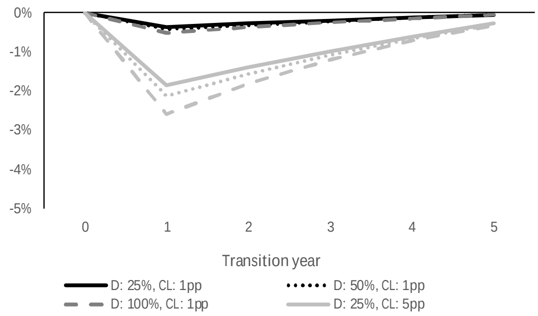
Panel A: Mining



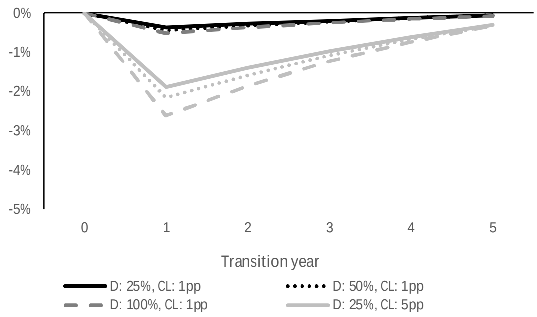
Panel B: Wood and paper products



Panel C: Chemicals and chemical products



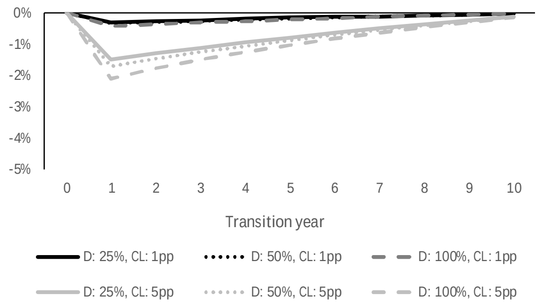
Panel D: Rubber and plastics



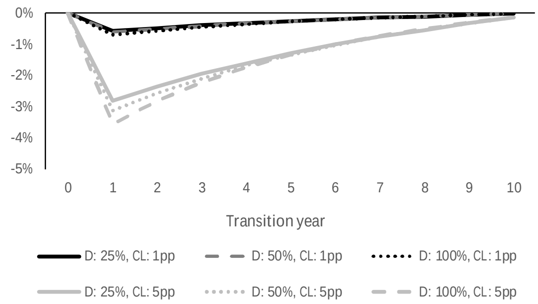
Panel E: Metals and fabricated metal products

Figure 4: Effects of capital losses, 5-year transition period, EU10.

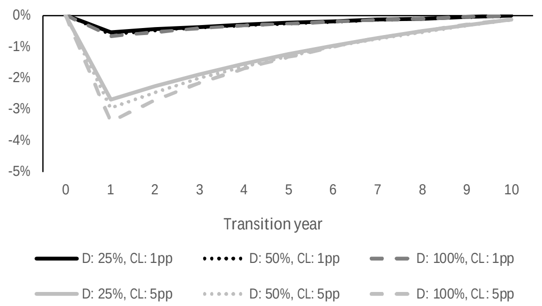
Note: D denotes an increase in the depreciation rate, and CL denotes a percentage point decline in the value of installed capital.



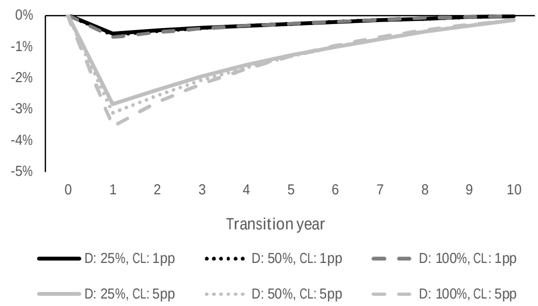
Panel A: Mining



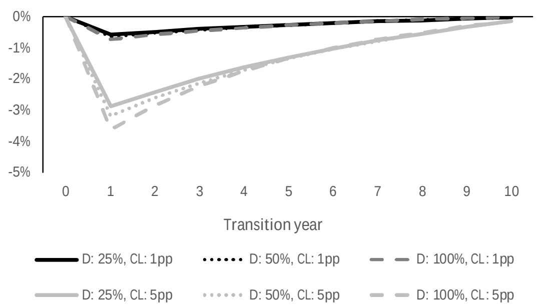
Panel B: Wood and paper products



Panel C: Chemicals and chemical products



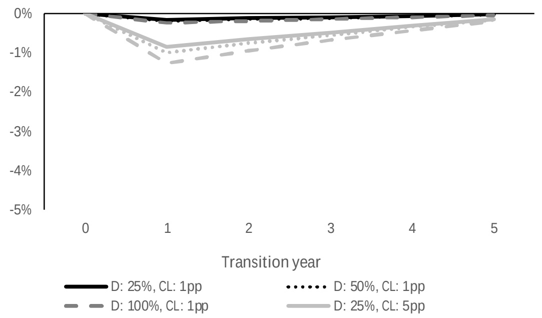
Panel D: Rubber and plastics



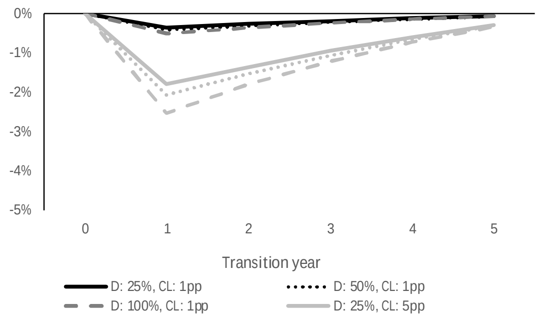
Panel E: Metals and fabricated metal products

Figure 5: Effects of capital losses, 10-year transition period, US.

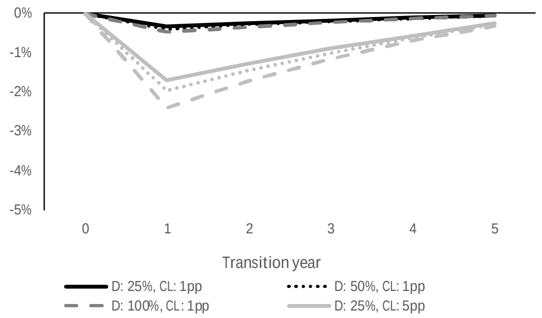
Note: D denotes an increase in the depreciation rate, and CL denotes a percentage point decline in the value of installed capital.



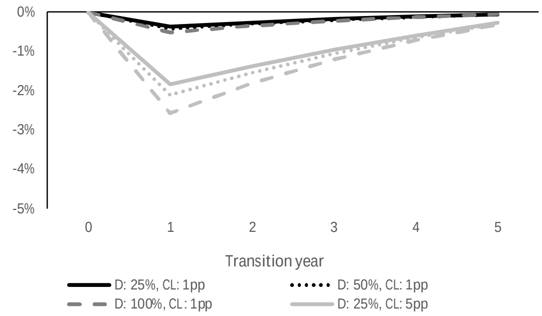
Panel A: Mining



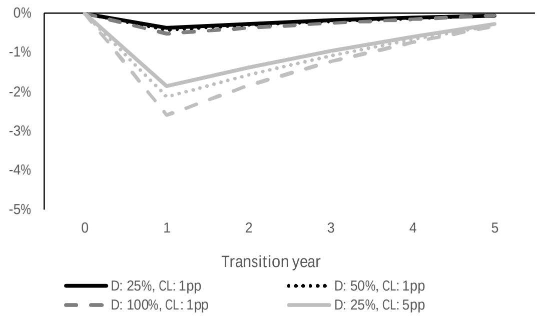
Panel B: Wood and paper products



Panel C: Chemicals and chemical products



Panel D: Rubber and plastics



Panel E: Metals and fabricated metal products

Figure 6: Effects of capital losses, 5-year transition period, US.

Note: D denotes an increase in the depreciation rate, and CL denotes a percentage point decline in the value of installed capital.

5.3 Three scenarios

Next, I combine the investment cost and the capital loss cost and calculate the total effect on the value of the industries using equation (2). The market value determines investors' willingness to invest in the industry and is thus a key metric. The more the market value declines, the lower the willingness to invest. For simplicity, I consider three scenarios: a scenario with low costs, involving an increase in the depreciation rate of 25% and no capital loss; a medium cost scenario, with an increase in the depreciation rate of 50 percent and a capital loss of 1 percent per year in the value of high-carbon capital during the transition period; and, finally, a high-cost scenario based on a 100 percent increase in the depreciation rate and capital loss of 5 percent per year.[7] For each scenario, I calculate the value of the firm using a 3 percent, a 5 percent, and a 10 percent depreciation rate. I assume that the depreciation rate is the same before, during, and after the transition period.

To explain the results, I compare the value of the industries with a benchmark, assuming that there are no costs associated with decarbonization. The profitability of the industries remains constant over time. To calculate the value of the industry, I assume that the return on capital without decarbonization is 3 percent per year, in line with the economy-wide average in the EU KLEMS database. Based on the depreciation rates in Table 2 and the capital losses/gains in Table 3, the capital compensation is calibrated to this level of profitability. I further assume that there is no growth and no change in the capital compensation over time irrespective of the scenario. This enables me to calculate the yearly profit and the market value of the industries under the assumption of no change in profitability.

Figure 7 illustrates the market value of the industries in the EU10 for the three scenarios in relation to the benchmark. The results for the US are shown in Figure 8. The results are expected given the previous results and similar across the industries and the two economies, with the exception of the mining industry. The reduction in the market value is between 5 and 100 percent depending on the assumptions. The average loss is about 25 percent. The main factor influencing the results is the discount factor. This is especially noticeable in the high-cost scenario, but the effect is similar across all the scenarios. In most cases, moving from the low-cost to the high-cost scenario with the same discount rate reduces the value of an industry

[7] It is reasonable to assume that there is a link between the net investment cost and the capital loss. The capital loss is likely to be higher when a larger share of the capital stock needs replacement.

by an additional 5 to 10 percent compared with the no-decarbonization case. An increase in the discount rate from 3 to 5 or from 5 to 10 percent may reduce the market value by 40 to 50 percentage points, at least in the medium-cost and high-cost scenarios.

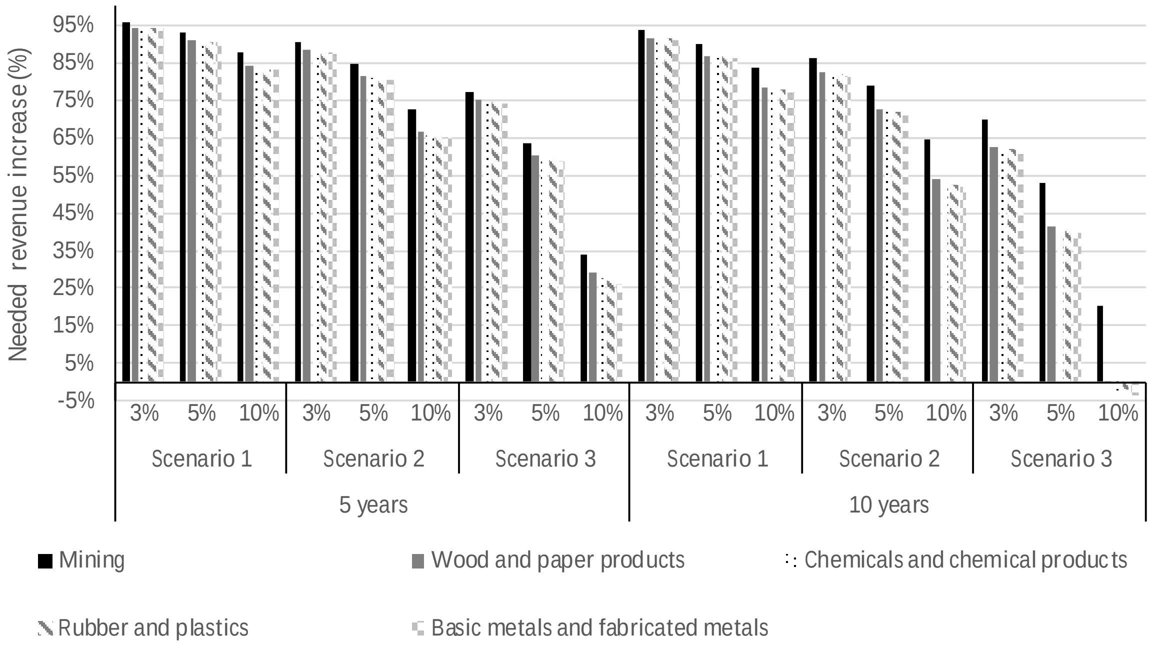


Figure 7: Estimated financial effects on the value of the ENRIs of decarbonization in the EU10.

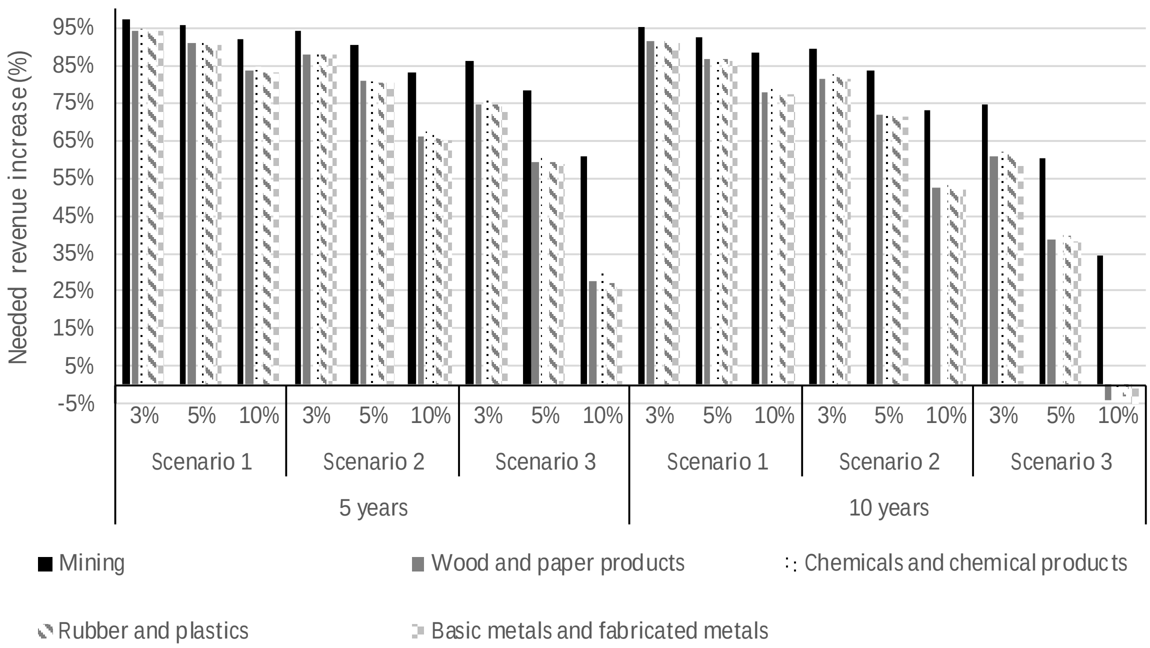


Figure 8: Estimated financial effects on the value of the ENRIs of decarbonization in the US.

The implication of this result is that the main obstacle to the ENRIs' ability to attract external capital to finance decarbonization is not the investment cost or the capital loss, although those factors are important, but the uncertainty about the future, which causes an increase in the discount rate. From a policy perspective, this implies that the main policy ambition should be to try and reduce the uncertainty.[8]

5.4 Financing decarbonization through greater capital compensation

So far, I have assumed that the level of net capital compensation is constant over time. Next, I consider the possibility of increasing the compensation through productivity and higher relative prices. Figures 9 (EU10) and 10 (US) illustrate the necessary increase in revenues to compensate for the reduction in the market value due to decarbonization. The revenue increase is calculated as the necessary increase in net capital compensation beginning in period 1 to ensure that there is no reduction in the market value of the industry compared with the benchmark case. For simplicity, I assume that the revenues increase to a new and higher level in period 1 and that this higher level is maintained thereafter.

[8] See for example Rodrik (2014) and Nilsson et al. (2021) for a discussion about the role of a green industrial policy in setting the direction for decarbonization and thus reducing uncertainty.

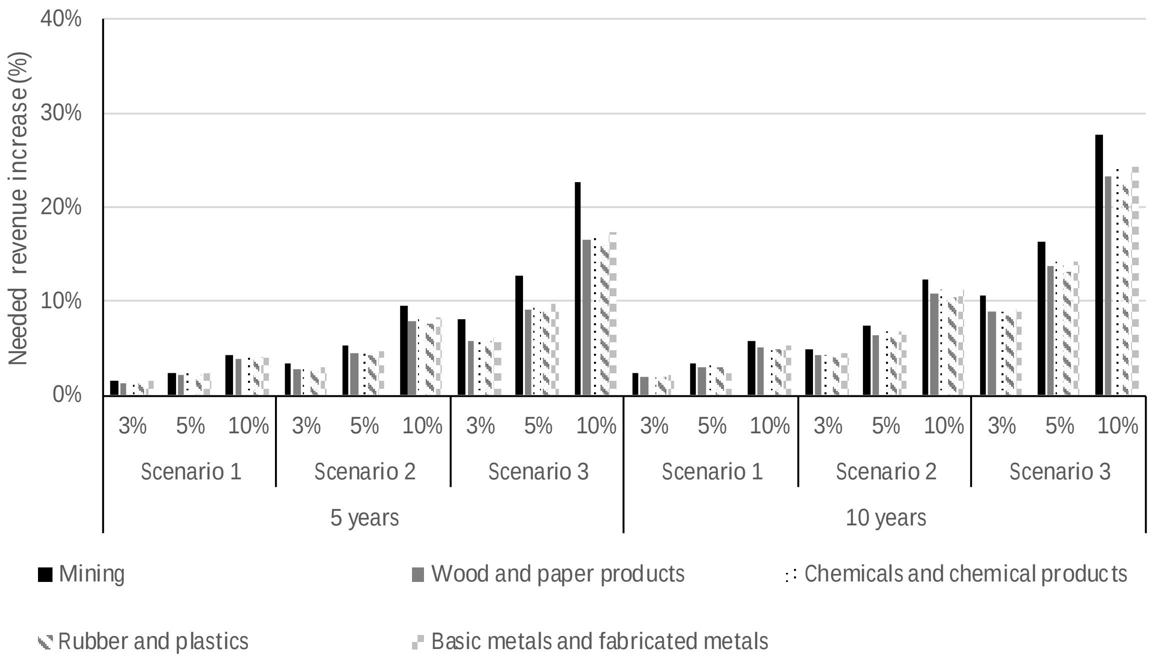


Figure 9: Estimated necessary revenue increases for three scenarios, EU10.

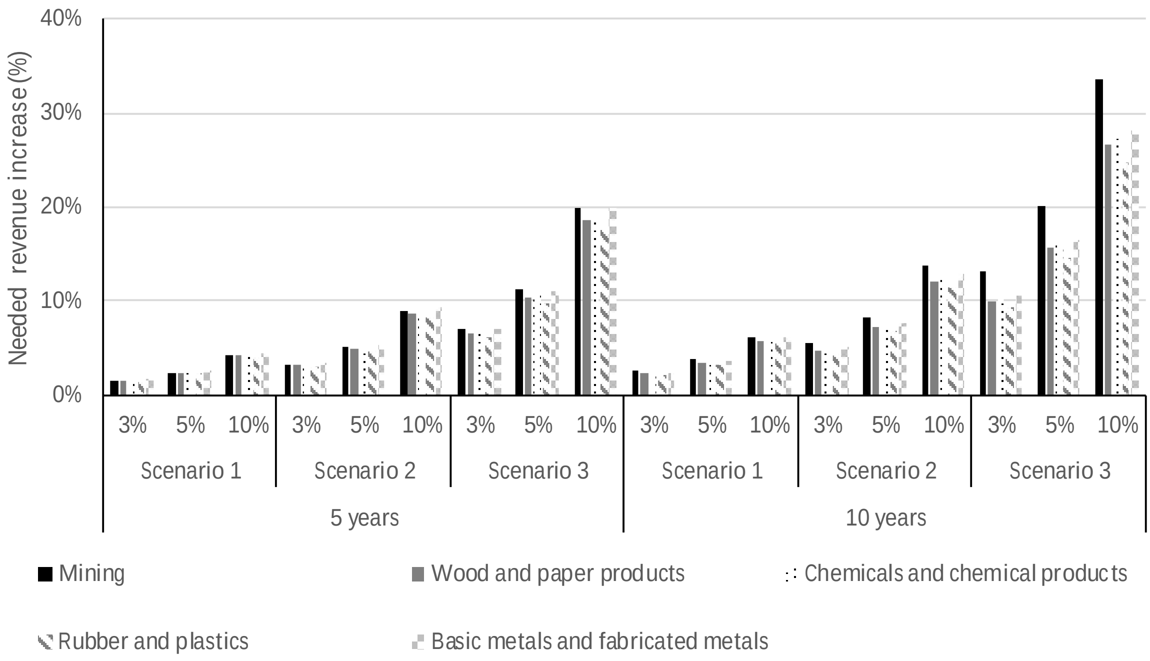


Figure 10: Estimated necessary revenue increases for three scenarios, US.

The estimated necessary revenue increase is relatively small: below 5 percent for the low-cost scenario, between 5 and 10 percent for the medium-cost scenario, and between 10 and 15 percent for the high-cost scenario. However, when the discount factor is 10 percent, the cost increases to 20 to 40 percent depending on the industry and the length of the transition period. As a comparison, the average capital productivity growth across all the ENRIs is roughly 1.5 percent per year. Such productivity growth over 5 years would increase the capital compensation by 7.8 percent, sufficient to compensate fully for the decarbonization cost.

Taken together, these results indicate that the possibility for the ENRIs to compensate for the relatively high decarbonization costs through higher productivity and higher relative prices is high. The ENRIs should be able to attract external capital to finance the decarbonization as long as investors are willing to make long-term investments in the industry and accept low or even negative returns on their investments during the transition phase. The only obstacle is uncertainty, or chasing short-term profitability, manifesting itself in a high discount rate. The recent trends toward a short-term rather than a long-term investment perspective are clearly a concern (see e.g. Bolton and Samama, 2013).

6. Conclusions

The main conclusion from my scenario analysis is that the effect of decarbonization on the profitability and market value of the ENRIs is likely to be modest, at least if investors take a long-term perspective and the level of uncertainty about the future is maintained within normal levels. Decarbonization will affect the industries' profitability in the short term. However, the loss of profitability due to higher investment costs and capital losses is likely to be relatively small even in the more extreme high-cost scenario that I considered. Provided that the industries can return to profitability after the transition period, it is highly likely that they will be able to offset most, or all, of the cost increase through higher prices and improved capital productivity. The ENRIs' ability to attract private capital to finance decarbonization is thus judged to be relatively high.

Although private financing of decarbonization is possible, policymakers still have a role to play in reducing uncertainty by i) providing directionality about the future of the industry (reducing uncertainty); ii) providing incentives for industries to modernize their production to enhance their productivity; and iii) promoting a long-term focus in investment decisions. An average yearly productivity growth rate of 1.5 percent, the average between 1997 and 2016, will go a long way toward compensating for the decarbonization costs. However, a future economy with little demand for new virgin materials may make it impossible for the ENRIs to compensate for the costs through higher prices and productivity alone. In this case, the government may have to step in and provide some financing.

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